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Advanced Modelling and Virtual Product Simulation in the Design and Build of Warships – A Practical View

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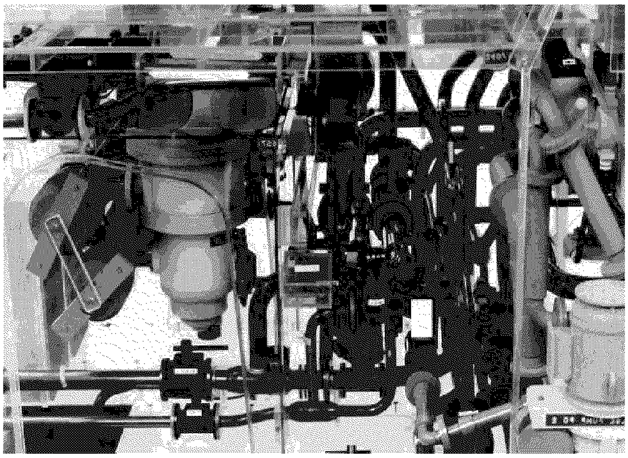
Overview

In considering 'Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Product Simulation' practical experience spanning five years of ship and submarine design and build was reviewed to seek quantification of the contribution made to cost reduction. It concluded that advanced modelling and virtual product simulation must be an integral part of the engineering processes to achieve an advantageous contribution to cost. This involves an effective design process and an efficient means of access to the appropriate product data supporting the geometric model/simulation technologies.
The application of Advanced Modelling and Virtual Product Simulation technologies is of limited value when used independently without the close association between the geometric models and the associated functional and physical data attributes which describe the requirement and design solution. This notion can also be illustrated in the traditional case of wood or scaled plastic physical mock-ups of ship or submarine layouts where modelled components were 'tagged' with a label description, or colour coded. i.e. orange to represent electrical routes, grey for HVAC and pre-defined colour codes for various pipe systems. Thus an advanced virtual model without any access to underlying data attributes is little more that a 'pretty picture'



1/5th. Scale Plastic Model - Colour Coded and Labelled

Paper presented at the RTO AVT Symposium on "Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation", held in Paris, France, 22-25 April 2002, and published in RTO-MP-089.

The use of Advanced Modelling to capture design layout arrangements and Virtual Product Simulation to verify the design offer an opportunity to optimise cost effectiveness when they also offer access to the design specification data, contract standards, rules and conventions, and supplier/vendor equipment information. Only then can model content and simulation behaviour criteria be specified and used with confidence to confirm that the functionality and operability of the design and its component systems meets the stated requirement.

Although the quantification of the cost reduction of products due to the introduction of Advanced modelling and Virtual Product Simulation is difficult to resolve, it is perhaps significant to note that the company workforce was reduced from c15,000 staff (in 1990) to c5,000 (in 1995/6). Due to the benefits of introducing new processes and supporting technologies the workforce has remained at the lower figure during a very busy period of design and build contracts for three surface warship designs (LPH, LPD ,AO) and the Astute Class nuclear powered submarine.

Introduction

When asked to present this paper the brief was to describe a commercial example of how virtual design, simulation and manufacturing tools are currently applied in the development of specific total products in the maritime sector. The paper thus presents the advanced modelling and virtual product simulation environment and practices used within BAE SYSTEMS Sea Systems division. BAE SYSTEMS have considerable expertise across the company in all fields of advanced modelling and virtual product simulation and actively encourage the appropriate technologies to be adopted across multiple sites through centres of excellence whenever they may contribute to a high quality product at an efficient cost.

Advanced Modelling and Virtual Product Simulation are often discussed by companies as being worthy of investigation or evaluation review in line with keeping up to date with the ‘latest’ technologies in a design environment. Although these technologies have been around in a stable form for several years, they are rarely accepted as a desirable or essential ingredient in support of the day to day design process and still have a reputation as a yet to be proven state of the art concept. As a result, many companies tinker with the technologies in a limited way, often just to show they are up to date with the evolving systems, or to impress potential customers, and they fail to commit the technologies as a required element of the design process. This reduces or eliminates any potential advantages that can be achieved with a structured and serious application of the technologies.

The design or manufacturing process is the key to achieving optimum cost effectiveness. Suitable technologies and systems can then be selected and applied if and when they are necessary and sufficient to support the process. Without a process requirement or a clear specification of deliverables and objectives the introduction of Advanced Modelling and Virtual Product Simulation reduces to the classic situation of chasing technology and seeking a problem on which to apply the technology solution, often with expensive failure. Technology researchers and developers need to consider this situation and evolve the technologies to achieve optimum modelling or simulation functionality, whilst retaining a managed interface to associated product data attributes. The objective should be to introduce advanced modelling and virtual product simulation as an integral part of the day to day processes within a company. To achieve this the systems need to be simple to use by engineers without the need for continued specialist support.

This paper outlines the experience gained since the introduction of Advanced Modelling and continued studies in Virtual Product Simulation at a Shipyard.

Company Background in Advanced Modelling and Visualisation

In 1993 BAE SYSTEMS Sea Systems in conjunction with Virtual Presence (formally Advanced Robotic Research Ltd.) and 13 major UK companies carried out research to address the maturity of the evolving Virtual Reality technologies with the objective of assessing their suitability for engineering use. Following a comprehensive review and several pilot studies using submarine model data, it was concluded that the technology was suitable and a system was procured for implemented in August 1997 at the ship and submarine yard in Barrow in Furness, England. Advanced Modelling and Visualisation technologies have been applied to all of the ship and submarine design build contracts since 1997 and are an integral component

of the design process. Engineers have access to visualisation tools on their desktop computing workstations and a purpose built Virtual Reality Suite was created for use as a design review facility with a capacity of up to 30 review staff. (a typical formal design acceptance review for a ship or submarine compartment will be up to 25 people including project engineers, customer representatives and approval bodies such as Lloyds)
The visualisation facilities and their use at the Barrow shipyard have been described as 'world leading' due to their integration into the design and production processes and for their heavy use on a day to day basis by the project design build teams. Project teams have booked the review room facilities on a constant daily use during the past five years, indeed during peak periods the facilities were booked from 6-00am to 10-00pm when the project worked a daily two shift schedule.

The design review facility at the Barrow site has the following facilities:

- A rear projected flat screen stereo capable display c 2.7m * 2m
  - Note: the flat screen display was selected in preference to the trend of curved screen VR projection display facilities now accepted as the norm. A flat screen was considered superior for reviewing complex pipe and equipment layout in ship and submarine compartment arrangements.
- Seating for up to 30 staff with acceptable viewing from all seats
- A projection control system to enable projected images from a workstation, a personal computer (including laptop) the Virtual Reality processor, and video. A sound system in also linked to the controller and provision is made for a microphone for the speaker (if necessary)
- A Reality Engine SGI processor
- A headset immersion and tracking system with 3-D mouse

In a typical design review meeting, a laptop PC will be used to provide a presentation of the meeting agenda and specific details or issues on the topic to be reviewed. This is supported by images of the design presented on the virtual reality visualisation tools and by live access to the product model database through the workstation. This combination of device displays offers powerful and comprehensive access to the design geometric layout and the underlying specification data.

Design Review Facility

Visualisation Technologies and their Use or Intent

In order to produce effective and efficient products at optimum build and operational costs, engineering design processes are evolving to replace traditional 2-D orthogonal drawings with 3-D geometrical models. The multi-disciplined 3-D geometric models and their associated attribute data used in complex product designs such as ships and submarines contain a very large volume of information to describe the component parts of the product and their function and geometric relationship in the layout arrangement of the design.

Access and recovery of data and information from this product definition model is often difficult and inefficient. The introduction of advanced modelling and visualisation technologies ensures that the design can be visualised effectively to verify feasibility and to confirm that the customer requirement has been met. There are several visualisation scenarios in a design environment each addressing a particular aspect of the design process. The requirement is to have an efficient, effective and easy to use facility to display and manipulate high data volume complex 3-D models for comprehensive review at each scenario level.

Functionality available and used at the Barrow shipyard includes:

- Desktop Processor (Small screen)
  The desktop processor visualisation environment is used to allow the engineers to review a model of the product around a desk with one or two colleagues whilst carrying out design discussions and or resolving design issues or uncertainties. This is a day to day tool used by all of the detail design engineers and is available on the 650+ workstations attached to the engineering data network.
- Large screen Projection
  A large screen projection facility enables a team of staff to collectively review the design in a formal or informal meeting and to collectively discuss design problems or issues. The use of projection onto a large screen in a meeting room has proven to be very effective particularly with a considerable number of review engineers (25 or more). It is specifically used for design area layout review and verification meetings leading to customer acceptance and design approval.
- Stereo viewing
  The addition of stereo capable projection to the large screen viewing enhances the visualisation capability by giving a sense of depth to the image that is extremely useful when reviewing complex design areas. The stereo visualisation when used in conjunction with large screen projection is highly recommended for inclusion in design review visualisation environments.
- Headset immersion
  Headset immersion is a specialist tool with useful functionality once its limits of accuracy are known and understood. However, it is not a technology used daily in the design process. Design Engineers and the customer have requested the use of the headset to verify specific design concerns for current contracts, the headset was then used complimentary to the large screen projection facility in design review situations.
- Rendering
  Use of rendering, colour and material textures to enhance the visualisation model is a very useful function when assessing or developing ship layout design. Rendering has been used to add some ‘realism’ to the 3-D model when necessary to assess the effect or operability of design issues. Examples include the use of material rendering such as proposed console displays in operations rooms and stainless steel or patterned fabrics on compartment bulkheads in operational and domestic areas to assess colour balance, ergonomics and operational human factor comfort. Texture functionality is also used to visually present optional design solutions that may be assessed by users (the Royal Navy) and the customer (MOD) where the options can be reviewed for comparison and discussion.
- Conference viewing
  Conference viewing is the ability for two or more engineers in remote sites to communicate and concurrently review a design model whilst discussing the issues by phone or videoconference. This facility is often available with visualisation software products and has a high potential in the modern trend to design products across several sites and/or partner companies.
- Event Simulation
  Event based simulation involving the animation of geometric models is a feature of visualisation that is not readily accepted by design engineers. Occasionally, event simulation behaviours have been added to ship layout design models to illustrate particular aspects of geometry movement such as opening of doors or removal of equipment from a complex area. However, the applications to date have been of limited value. There is potential for event based simulation technology to be used in the design process if the input of the simulation behaviours can be in simple format (i.e. tabular) or can be imported from the result files from dedicated simulation tools.
- User Driven

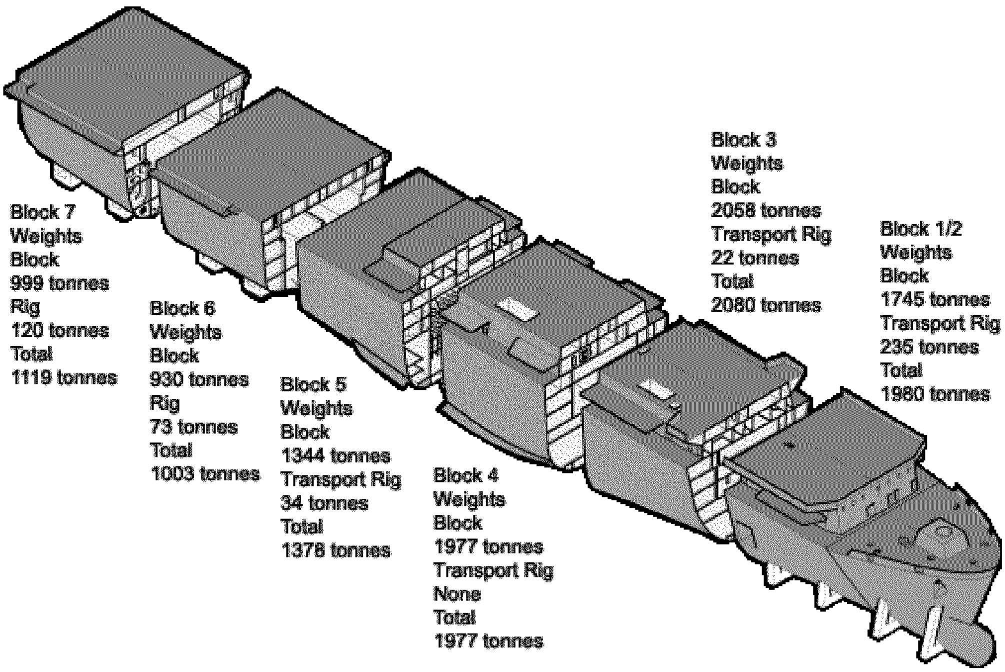
The success of acceptance of the visualisation technologies into the design process is a direct result of the ‘user driven’ philosophy in which the project design engineers are trained and sufficiently competent with the technologies to use them regularly without the need for specialist support. In addition, a simple and effective

means of input of design models into the visualisation system enables design review data to be prepared efficiently in minimum time for use in discussions or meetings.
The design is developed using 3-D CAD models with an associated product database and the visualisation tools enable the engineers to retrieve the design layout geometry for any selected area of the vessel and prepare it for design review visualisation and discussion.
It is important to state that models are not created explicitly for visualisation. 3-D Models are created during the design process and then reviewed using visualisation tools. To create separate models for visualisation or virtual prototyping is an unacceptable concept in terms of cost, schedule, data integrity and design control.

Practical application of VR technologies

During 1995 a Business Improvement Project identified several areas to be addressed to improve the effectiveness of the company. They included a considerable change of culture in the existing working practices and design and build processes. In support of these new processes a number of systems were implemented to capture, control and manage product information. As a result, the LPD (Landing Platform Dock) surface warship contract was the first design build project to attempt a 100% digital definition and subsequently the first to use visualisation technologies for formal design acceptance by the customer. The significant changes in company practices and the introduction of advanced 3-D CAD modelling, product data management and visualisation technologies create the difficulty in quantifying the effects of the visualisation and virtual product model tools on the overall performance of the project.

The LPD ships had a build strategy based on seven large ‘block’ assemblies which were fabricated and outfit to an advanced state in the shipyard build hall and then moved across site to the launch slipways where they were connected to the adjacent blocks. This build strategy was supported by a design strategy that converted the functional design requirement into design areas matching the block breakdown. Design engineers together with production, procurement, logistics support, systems engineers, specialist professional and the customer formed teams for each design area. Advanced Modelling and Virtual Reality technologies were used extensively for formal and informal design reviews on a daily basis as the project design evolved.

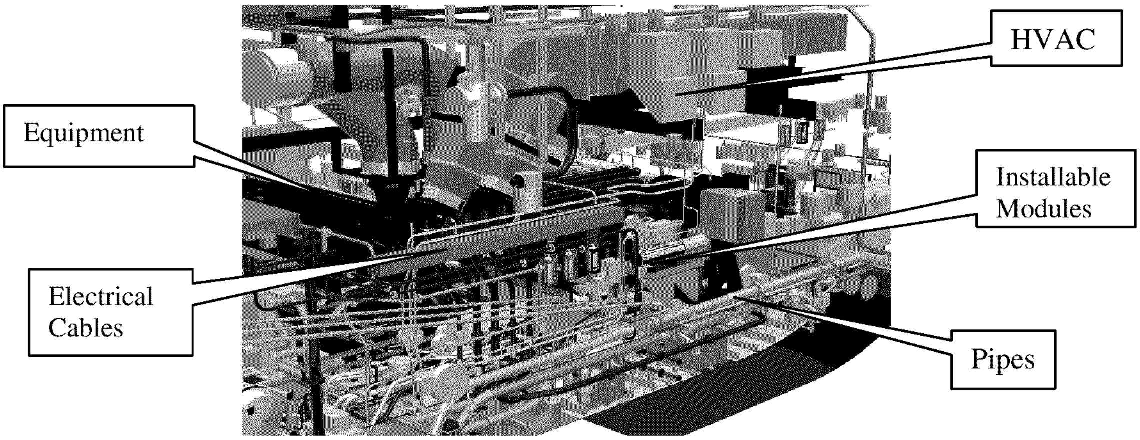


LPD Block Breakdown

The design layout is modelled in 3-D geometry based on a product structure tree that can be used to selectively view a section or the entire area as necessary for the design or review. The design is developed

with consideration from all aspects of the business and advanced modelling technologies enable the review teams to assess and influence the design throughout its evolution. In particular, the production engineering aspects of design are considered to optimise the use of equipment modules, identify when to outfit items for cost effectiveness and develop an installation plan to suit the build strategy.

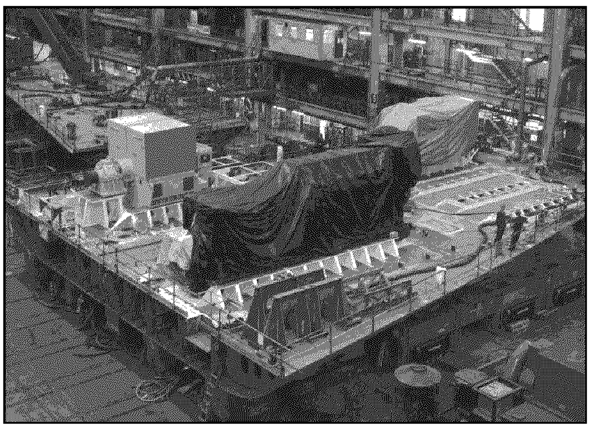
The production planning activities carried out during the design process enable the design and production requirements to be merged to achieve cost effectiveness and efficiency. Any design issues or identified production problems are resolved using visualisation of the model and simple simulation of equipment movement, access for the workforce and manipulation of required tools etc is assessed.



Typical 3-D Geometry Model

This facility was extensively used in the LPD project for the first time with variable levels of success. In shipbuilding, a critical consideration of the build and outfit process is the necessity to ensure that all major items are installed in the structure assembly prior to it being 'closed' by installation of the bulkheads and deckhead. i.e. Major equipment must be installed on the ship prior to the compartment boundaries being sealed, otherwise large holes need to be cut in the structure to ship these components causing potential structural weakness of the vessel. The models and associated data enabled these issues to be resolved successfully.

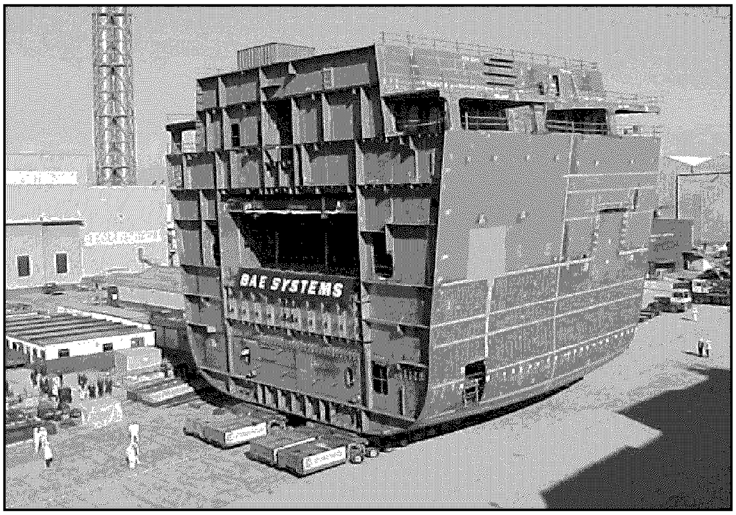
The following sequence of images illustrate the build process, which had a considerable contribution from the use of the modelling reviews which ensured the build sequence was optimised for the block build philosophy.



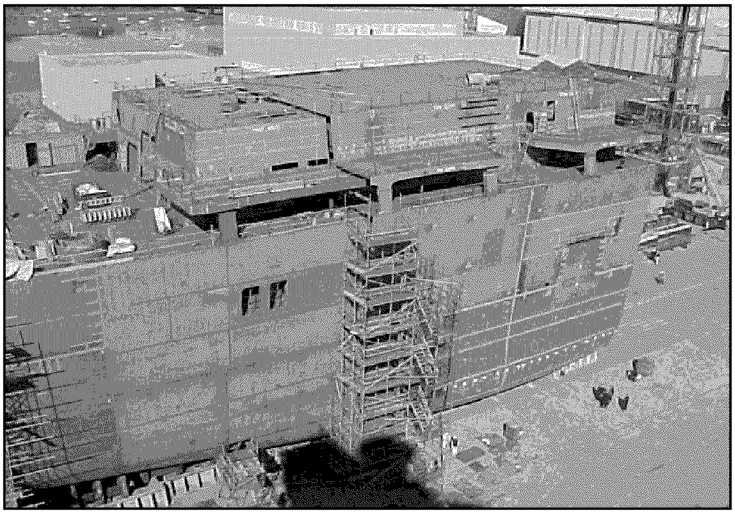
Block Build – All major equipment fitted

Full block build with advanced stages of outfit

The Build Blocks and their fabricated sub-units are a large complex and heavy assemblies which require production engineering effort in the provision of temporary supports, jigs and rigs for the build and movement of the blocks. This is particularly relevant for the extreme forward and aft blocks that often have narrow structures at the base and overhanging steelwork towards the top of the block. This together with the weight and centre of gravity considerations involves the design and build of suitable transportation rigs that enable the block to be moved safely without restricting the access required to line up the block with its adjacent block in the build hall or at the berth. Advanced modelling can help visualise these issues and solutions.



Block movement from Build Hall to Berth



Block matched to adjacent one on berth

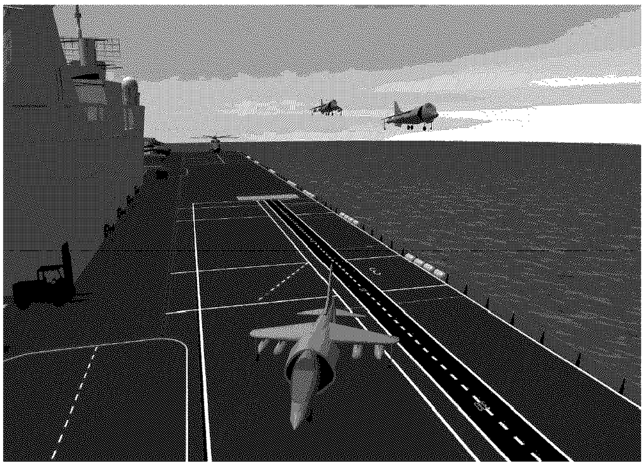
The second surface ship contract, involving two Auxiliary Oil Tankers, also used the developing processes and the systems applied to the LPD and the visualisation and virtual prototyping tools for internal and external design reviews.

The Astute class project is the first submarine design to use the technologies. Submarine design in the past has been supported by physical prototypes of either a full size wood mock-up or a scaled plastic model, both of which are expensive to produce in time and cost and which have an considerable effect on project schedule. The scaled prototype physical model was a representation of the design layout with sufficient accuracy for direct extraction of production details. (to feed Numerical Control Machine tools for pipe bending, for example). Elimination of the physical prototype will result in considerable cost, time and schedule saving. The Astute project has declared that advanced modelling and virtual prototype technologies will replace the physical model.

Concept Design Studies

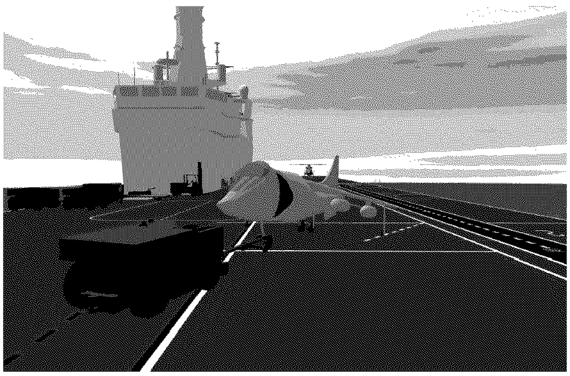
The concept design phase of a project is such that 80% of the costs of the design are committed at this stage in the process.

In addition to the current design build projects, Advanced Modelling and Virtual Product simulation tools are used in concept design studies for future ships. The use of a product structure tree enables a design to be developed with several options included and a selection of options chosen as one possible design solution. Alternative design options can be selected and reviewed as necessary to assess the strengths and weaknesses of each configuration. If all of the selected design options are then analysed using simulation studies, a optimum design can be identified from the feasable alternatives.
Advanced Modelling and Virtual Prototype Simulation are particularly useful at the concept design stage and several studies have been carried out in conjunction with the MOD and industrial partners in the effectiveness of aircraft carrier flight deck layout and its relationship with aircraft operations. These studies involved use of flight simulators to control the behaviour of the aircraft and ship sea state simulators to control the behaviour of the ship in varying conditions. Pilot opinions were sought for the layout of the flight deck for manoeuvring, take-off and landing. The operation of the aircraft was directed by voice (telephone) contact between the pilot and a 'shipboard' flight controller, who gave permissions for taxiing, take-off landing etc as per normal aircraft carrier routine at sea.



Aircraft Flight Simulation with Aircraft Carrier Model

A secondary simulation study included analysis of aircraft manoeuvring by ship crew using hangar and flight deck towing equipment, verification of the refuelling facilities and assessment of the weapons handling and aircraft preparation activities. These studies used a mix of kinematics simulation and human factor manikin simulation.



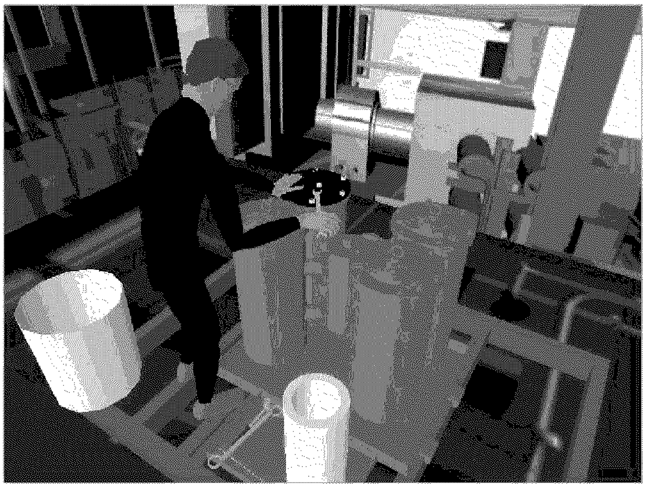
Tow-truck Simulation Model

Actual Tow-truck

When combined, these simulation studies offer a comprehensive understanding of the aircraft to ship interface critical to the design of a carrier, and is being done twelve years before the ship is due to be delivered. The ability to assess the relationship between a developing aircraft design and a ship concept design enables the critical issues to be resolved at this early stage and will lead to reduced long term cost.

Human Factors - Manikin Simulation.

Human Factor issues are evolving as critical requirements in design contracts. However, the technologies available in support of human factor design studies are limited, complex to use, and often involve data conversion processes often causing data inaccuracies. The requirement for human factor studies has been addressed at the Barrow shipyard in several alternatives. Simple manikin representations of typical human forms in fixed positions such as standing, sitting, crouching etc. are used to indicate a sense of scale in the 3-D models of ship compartments and give an early indication of design feasibility. More advanced manikin representations are used to assess operational positions in the design or the ability to construct parts of the ship or submarine that may be difficult due to access problems, density of surrounding components or services, or the need to carry or otherwise ship specialist tools. Both of the above technologies are used regularly by the design teams.
Additional studies have been made on the use of mathematically accurate manikin systems to evaluate their functionality and usefulness as aids in the design process. For example, a recent study involved the evaluation of two maintenance activities on the LPD project. The objective was to understand the feasibility of manikin simulation tools as an in-service support training aid. The study involved the change of oil filters for the ship diesel engines, and the more complex task of removal of a cylinder head from the engine. To carry out the studies, the 3-D models for the design were modified to include the internal component parts used in the maintenance task as these items are not normally modelled for design layout with experienced Human Factor engineers from NNC (formally a company subsidiary) carrying out the simulation. The study involved the manikin locating tools and spares, approaching the work and carrying out a known sequence of operations for the task. The study was to show access to the work, handling of tools and equipment and the process for the task. Unexpectedly the study identified design issues affecting the maintainability of the ship including the lack of secure dry storage for tools and replaceable items such as nuts, washers, spacers etc. and the difficulties of access to the rear of the cylinder head due to lack of suitable step or platform. The simple study thus illustrated that the technology potential when used in consideration of design for maintainability.



Manikin Study – Design For Maintenance

Measure of Success

One measure of the success of the application of the advanced modelling and virtual product simulation implementation at the Barrow shipyard is the decision by the design projects to build similar facilities to overcome the high demand. Three other facilities are thus in the process of being procured for project use. An alternative measure of success is the effect of advanced modelling and virtual product simulation in the consideration of design options in the concept and early stages of design. Issues that were often debated and

discussed using traditional design methodologies are often now readily accepted from the initial model visualisation and the design engineers spend their time more productively discussing new issues or proposals rather than verifying the ‘old’ issues.
The introduction of the technologies to the concept design stage of the design process has been successful in defining feasible solutions quickly and ensuring that the customer and users can understand the design concept. Discussions and concerns are considered against optional solutions, and each is assessed against outline requirements even at this early stage.
On all current projects the use of advanced modelling and virtual product simulation technologies has enabled the design teams to regularly assess and discuss the design layout and operability through informal and formal reviews. A key factor in this success is the philosophy of a user driven facility that can be used at any time by the project teams without the need for specialist support. This has been achieved by incorporation of an integral data conversion tool, technologies which are easy to use and operate, and integration of the visualisation facilities as one of the processors on the engineering network giving efficient access to files and models.
As stated earlier, the quantification of the effect on cost reduction directly attributed to the modelling and simulation technologies cannot easily be extracted from the general contribution made by improved design processes and the supporting systems. However, if the application of the technologies was shown to have a negative effect on the design, manufacturing, schedule or cost of the projects, they would not have continued to use the review facilities each day over the past five years.
The use of Advanced Modelling and Virtual product simulation has resulted in customer agreement to formally approve and sign-off the design via visualisation reviews of the models. This is a considerable success and partially due to the customer access and involvement with the models throughout and design process, acceptance meetings are now more productive as most key issues have been resolved prior to the review.
The illustration and verification of build strategies has also been successfully addressed using the technologies with resulting build sequences being developed and design areas selected to suit build requirements improving efficiency in the manufacturing process.
The studies into simulation based design have also been a success and have proven the concept and usefulness of this technology.
A final consideration in the successful application of advanced modelling and virtual product simulation is to use the technologies as a key element of the design process. It is not acceptable for a design to be developed using 2-D drawings or other technologies and then recaptured using advanced modelling. This creates rework, leads to data errors, affects the control of the design, and brings doubts into the quality, maturity and integrity of the resultant model.

Major Issues

Contrary to the success of the application of Advanced Modelling the following issues must still to be addressed:

- Geometric data is not sufficient to define a product, improved access is required from the geometry to the underlying specification, functional and component data.
- Database contents, data quality, data search and retrieval technologies are critical in the quest to reduce costs and are constantly being reviewed based on experience from the projects
- Geometry models must be controlled at component level for optimum management of the design options, use in simulation tools, and application throughout the scope of the life cycle.

Improvements

In applying the technologies, the successes outlined above have been realised on real, complex, high volume design projects. However, there is considerable scope for improvement in the use of the technologies including further development of user awareness of the functionality available to enhance the work already being done, improved access for the models to the underlying data attributes and information, and development of modelling strategies to suit simulation based design.
Simulation although often used in design analysis is still not strongly associated with advanced modelling visualisation and needs to be progressively introduced into the process following the results of the studies.

Introducing Advanced Modelling and Virtual Product Simulation technologies as an integral component of the design lifecycle management process is also being undertaken to help resolve some of the outstanding issues identified when analysing the lessons learnt from the design build projects.

Summary

The application of Advanced Modelling and Virtual Product Simulation at the Barrow shipyard has been a considerable success, with the design review and virtual reality visualisation facilities used constantly since their introduction in 1997. Advanced modelling is a day to day technology used by all design and detail engineers involved in the design process. The design review facility for large numbers of staff to collectively review the design layout models has a success measured by its constant demand by the projects, and the decision for new projects to build similar facilities. The technologies have been applied as a real and useful design tool on all projects since 1997, including concept designs and future projects bid preparations.
The requirement for improved access to underlying database information from the models is an issue that is being addressed to improve the use of the technologies.
Simple simulation such as animation of the geometric models and use of simple manikins is used regularly by the projects, however the development of a strategy for the implementation of further simulation applications is proposed following the success of the trial studies.
As a practical example of commercial use of Advanced Modelling and Virtual Product Simulation, the BAE SYSTEMS Sea Systems implementation illustrated above has shown that the technologies can be used effectively and efficiently, and can become an integral part of the design life cycle.

Conclusion

The requirement for the Reduction of Military Vehicle Time and Cost through Advanced Modelling and Virtual Product Simulation is an objective that is difficult to achieve on its own without improvement of design processes, lifecycle management, and well structured product databases with effective data access. However, Advanced Modelling and Virtual Product Simulation can offer a significant contribution to the optimisation of design solutions. In particular, use of the technologies in the concept and early stages of design, will influence costs considerably.

Paper Keynote #4
Discussor's name J. Coyle
Author John Martin

Q: Are you using the visualization data for delivery of information to the factory?

A: Production is very heavily involved in the development process and uses the data directly